

**APPLICATION FOR UNITED STATES
LETTERS PATENT**

**VIA AND VIA LANDING STRUCTURES FOR SMOOTHING TRANSITIONS IN
MULTI-LAYER SUBSTRATES**

Inventors:

Modest Oprysko

Lei Shan

Jeannine M. Trewhella

**VIA AND VIA LANDING STRUCTURES FOR SMOOTHING TRANSITIONS IN
MULTI-LAYER SUBSTRATES**

BACKGROUND OF THE INVENTION

5 **1. Field of the Invention**

The present invention relates to integrated circuits, and more particularly to circuit structures, which provide smooth transitions in multi-layer substrates.

10 **2. Description of the Related Art**

Multi-layer structures often include a plurality of electrical connections. The metal lines or conductive landings between structures may or may not share a common layout scheme. In such structures, transitions and connections between these structures may prove difficult and are often a source of performance issues.

In multi-layer substrates such as a Ball Grid Array (BGA) package, via structures as well as transitions from a C4 or wirebond pitch (~225um) to a BGA or other pin pitch (~1000um) become the bottlenecks of electrical performance. These bottlenecks are compounded with ever increasing operating speed. A via size/spacing that is selected for matching a system characteristic impedance at the C4 or

wirebond end of a package tends to result in much higher impedance at the BGA end. This impedance variation is detrimental particularly when via length is larger than 1/10 of a propagation wavelength, noting that the
5 wavelength decreases with the increase in operating frequency.

For example, in a 2mm thick alumina substrate, the critical frequency is about 5GHz, and this critical frequency decreases with the increase of substrate
10 thickness. Issues arise with 6Gb/sec server and network switching links are emerging in the near future, and with many communication and testing applications targeting 40Gb/sec and above.

15 **SUMMARY OF THE INVENTION**

An integrated circuit arrangement or package includes a set of contact pads arranged in a pattern and a multi-component conductive structure, which electrically connects the set of contact pads to at least one signal line. The
20 conductive structure provides impedance matching between the pads and the at least one signal line.

These and other objects, features and advantages of the present invention will become apparent from the following

detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

5 **BRIEF DESCRIPTION OF DRAWINGS**

The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

10 FIG. 1 is an illustrative side view of a chip mounted on a printed wiring board in accordance with the present disclosure;

FIG. 2 is a perspective view of a standard via structure for connecting contacts to pads in accordance with the prior art;

15 FIG. 3 is a perspective view of a double via structure for connecting contacts to pads in accordance with the present disclosure;

20 FIG. 4 is a perspective view of a direct via structure for connecting contacts to pads in accordance with the present disclosure;

FIG. 5 is a perspective view of an offset via structure for connecting contacts to pads in accordance with the present disclosure;

FIG. 6 is a perspective view of an inline pyramid via structure for connecting contacts to pads in accordance with the present disclosure;

FIG. 7 is a perspective view of a parallel pyramid via structure for connecting contacts to pads in accordance with the present disclosure;

FIG. 8 is a chart showing insertion loss versus frequency for the structures of FIGS. 2-7;

FIG. 9 is a view of a test configuration used to obtain the data of FIG. 8; and

FIG. 10 is an eye-chart showing error free operation using the structures of the present disclosure.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Via structures and landings disclosed herein provide smooth transitions within multi-layer substrates. This assists in avoiding reduced performance due to operational frequency limitations. Multi-layer substrates may be employed in a variety of different applications, such as for example, packaging of semiconductor chips and chips set, integrated circuit boards with chips mounted thereon,

chips having multiple substrates and related applications.

In one embodiment, pyramid vias and via landing structures are disclosed to provide smooth via and pitch transitions within multilayer substrates. These provide substantially continuous impedance structures and therefore extend existing packaging solutions to much higher frequency applications. The disclosed structures are fully compatible with existing substrate manufacturing processes with little or no additional costs for implementation.

Referring now in detail to the figures in which like numerals represent the same or similar elements and initially to FIG. 1, an illustrative chip mounting setup is illustratively shown. A chip 2, for example, a semiconductor chip, is mounted or otherwise connected to a multi-layer substrate 4 through transmission lines 24, which connect to C4 joints 25. Multi-layer substrate 4 includes via structures 21 which connect to BGA joints 16. The present invention will illustrate a plurality of different via structures for multiplayer substrate 4. Joints 16 provide an electrical path to conductive structures 12 formed on a printed wiring board 6. The setup shown in FIG. 1 is illustrative of one setup that can benefit from the

embodiments of present disclosure. Other embodiments and setup are also contemplated.

Referring to FIG. 2, standard via and landing structures are for multi-layer substrate 4 shown in accordance with the prior art to provide a comparison to the structures of the present disclosure. Metal lines or waveguides 12 are provided on a printed wiring board (PWB) 6. BGA joints 16 are formed connecting to lines 12 and are depicted as cylinders in FIG. 2. A dielectric or air gap 18 is provided as a standoff for BGA joints 16. Vias 20 are formed through dielectric layer 22. Transmission lines 24 (which connect to C4 joints 25) are connected to vias 20. At higher frequency operations of structure 10, performance degradation is experienced due to impedance mismatches as a result of the size discrepancies between vias 20 and connected conductors (e.g., joints 16, lines 12 and lines 24). While this structure is relatively easy to manufacture, the structures is less compatible with high-speed operations.

Illustrative embodiments will now be described with reference to FIGS. 3-7. While these embodiments are illustrative of the concepts of the present disclosure, they should not be construed as limiting the present disclosure.

Referring to FIG. 3, one embodiment, which may be called a double via structure, is shown. Metal lines or waveguides 106 are provided on a first substrate 102. Substrate 102 may include, for example, a PWB or other structure. Via landings or joints 108 are connected to lines 106, which be formed on substrate 102. A dielectric or air gap 104 is provided as a standoff to permit landings (108) to be connectable to vias 110 formed through dielectric layer 112. Vias 110 are doubled-up within multiplayer stack 101 in this embodiment, that is, two for each landing 108. It is also contemplated that more than two vias 110 be provided for each landing 108. Vias 110 may each include a 660 μ m long, 62 μ m diameter via. Other sizes may also be employed.

At the top of via structures 110, a finite ground plane coplanar waveguide (CPW) 114, e.g., a 50-Ohm transmission line, is employed to connect to C4 joints of a chip (not shown) to the vias 110. Transmission lines 114 may include a signal line surrounded by two ground lines, may include two signal lines or any other combination of ground lines and signal line or lines.

The double via structure is employed on each

interconnect to lower via inductance and to increase via coupling capacitance, which adjusts the characteristic impedance (e.g., towards 50 Ohm) and therefore improves impedance match.

5 Referring to FIG. 4, a direct via structure is illustratively shown. In this multi-layer structure 201, vias 120a and 120b are over or in close proximity of landings 108. Adjacent landings 108 include a teardrop or other gradual-shaped conductor 122 to permit vias 120a to be
10 located closer to via 120a. In this way, vias 120a and 120b are located close to one another to affect the capacitive coupling therebetween. Parallel Ground-Signal-Ground (GSG) vias (to lines 114, which are ground, signal, and ground in this illustrative example) are spaced so that a given
15 impedance is obtained (e.g., 50 Ohm). Teardrop-shaped conductors 122 are used to fan-out the ground via to corresponding pads/landings 108 to minimize coupling capacitance.

 Referring to FIG. 5, an offset via multi-layer
20 structure 301 is illustratively shown. This structure is similar to the direct via structure of FIG. 4; however, the vias 130 are offset from a centrally located landing 108 by

conductors 132. The "offset via" is similar to the "direct via" except that the via 130 lands in between two rows of landing pads or joints 108 (a second row of pads 108 not shown). A short taper CPW-like structure 132 is inserted
5 to smooth the transition with continuous impedance.

Referring to FIG. 6, an inline pyramid via structure 401 is illustratively shown. This structure remains in-line over landing pads or joints 108. In the embodiment shown, double vias 148 and 154 (more vias may be employed) make
10 contact with pads 108. An intermediate level conductor 146 is patterned to connect vias 148 to vias 144. Vias 144 are then connected to conductors 142, and vias 140 connect to line 114. The conductive path of the outer landing pads 108 is moved more centrally in a step-wise manner using a series
15 of vias (140, 144) and conductive connections (142, 146). It should be noted that a greater number (or lesser number) of conductive steps/layers may be employed to achieve improved results over the prior art. Two or more vias may be employed at each connection point although only one or two
20 are illustrated in FIGS. 3-7.

Over centrally disposed pads 108, a conductive path including vias 150 and 154 and conductor 152 is formed to

connect to a centrally disposed line 114. In the case of an inline pyramid structure 401, the impedance control is achieved through vertical via stack structures, which increase the number of vias as the spacing grows down toward pads/joints 108.

Referring to FIG. 7, a parallel pyramid via structure 501 is illustratively shown. This structure remains in-line over landing pads 108; however, via pairs 160, 164 and 172 remain in a parallel orientation to lines 114. In the embodiment shown, double vias 160 and 164 (more vias may be employed) make contact with pads 108. An intermediate level conductor 162 is formed to connect vias 160 to vias 164. Vias 164 are then connected to conductors 166, and vias 168 connect to line 114. The conductive path of the outer landing pads 108 is placed more centrally in a step-wise manner using a series of vias (160, 164, 168) and conductive connections (162, 166). It should be noted that a greater number (or lesser number) of conductive steps/layers may be employed to achieve improved results over the prior art. Two or more vias may be employed at each connection point although only one or two are illustrated in FIGS. 3-7.

Over a centrally disposed pad 108, a conductive path

including vias 170 and 172 and conductor 174 is formed to connect to a centrally disposed line 114. In the case of parallel pyramid, the impedance control is achieved through vertical via stack structures, which increase the number of vias as the spacing grows down toward pads 108.

Referring to FIG. 8, the illustrative via structures of this disclosure, including double via, direct via, offset via, inline pyramid, and parallel pyramid were modeled and tested by the inventors. To various extents, high frequency performances were improved over a standard via layout according to both simulation and measurement results.

As an example to demonstrate the improvement, FIG. 8 includes the models of these five via structures compared with a standard via layout. FIG. 8 shows insertion loss (dB) versus Frequency (GHz) curves for a standard via 206, double via 204, direct via 202, offset via 200, inline pyramid 208, and parallel pyramid 210.

For the multi-layer stack, an 8-layer stack alumina substrate and 660 μ m long 62 μ m diameter vias were used for

the model setup. At the top of these via structures, a 50 Ohm finite ground plane coplanar waveguide (CPW) was adopted to connect C4 joints of a chip to the vias, and a 50 Ohm microstrip line on an organic test card was used to connect the BGA balls to coaxial connectors. (see e.g., FIG. 1)

A performance comparison based on 3D FEM (HFSS) simulation results (FIG. 8) conveys the insertion loss in dB as a measure of signal power loss over the modeled structures. In this case, -5dB or 70% power loss is used to estimate the improvement of the disclosed structures over standard via layout (206). Compared with the 23GHz of standard via layout, the frequency response is surprisingly increased up to 36GHz for double via 204, 40GHz for direct via 202, and 45GHz for the rest of the three structures (offset via 200, inline pyramid 208, and parallel pyramid 210).

The improvement is significant and provides for the implementation of high speed interconnects using existing packaging solutions. For those applications with more layer

stacks and thicker substrates, the improvement should be even more pronounced over standard via layout when moving towards the lower frequency range.

Referring to FIGS. 9 and 10, in addition to the
5 insertion loss measurements on prototype packages, which support the observations from simulations (e.g., FIG. 8), an assembled package 300 with a multiplexer circuit chip 302 (FIG. 9) and a test carrier 304 was operated at 40Gb/sec data rate free of error. An 8-layer stack alumina
10 substrate 306 (below chip 302) with 660 μ m long 62 μ m diameter vias were used for the multi-layer setup. At the top of these via structures, a 50 Ohm finite ground plane coplanar waveguide (CPW) was adopted to connect C4 joints of a chip to the vias (see also FIG. 1), and a 50 Ohm microstrip line
15 on an organic test card 304 was used to connect BGA balls (FIG. 1) to coaxial connectors 308.

A 40Gb/sec eye-diagram (FIG. 10) is shown at the output of the test carrier, and as reported, through low cost commercial packages, error-free high frequency
20 operation can be performed in accordance with the present

disclosure.

The multi-layer transition stack structures of the present disclosure provide alternative impedance magnitudes, which can be matched to the chips and PWB in accordance with the needed characteristics. The stack may be optimized to the requirements of each chip/PWB combination, and the structure and its characteristics, e.g., impedance, geometry (thickness and electrical connection positions), etc. may be determined and selected for each situation.

Having described preferred embodiments of a via and via landing structures for smoothing transitions in multi-layer substrates (which are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the invention disclosed which are within the scope and spirit of the invention as outlined by the appended claims. Having thus described the invention with the details and particularity required by the patent laws,

what is claimed and desired protected by Letters Patent is set forth in the appended claims.